A Retail Model for Assessing Demand at Supermarkets in England, Scotland and Wales

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The model is a standard Lakshmanan and Hansen (1965) form[1] which in the terminology of spatial interaction models is singly-constrained to reflect the fact that shopping trips generated from residential areas – origins zones – are conserved while enabling predictions to be made at destinations which are supermarkets of different sizes. The model is disaggregated by age cohort a and it is assumed that each age cohort has its own measure of travel behaviour which is reflected by the fact that different age groups respond to travel costs between origins and destinations differently. The model can be defined as

$$S_{ij}^{a} = E_{i}^{a} \frac{A_j \exp\left(-\beta^{a} c_{ij}\right)}{\sum_j A_j \exp\left(-\beta^{a} c_{ij}\right)} \quad , \quad \sum_j S_{ij}^{a} = E_{i}^{a}$$

where S_{ij}^{a} is the expenditure by age group a from residential zone i to shopping centre j, E_i^a is the expenditure available to shop at residential zone i for age group a, A_j is the attractor of the supermarket at j yet to be specified, c_{ij} is the travel cost from residential zone i to supermarket at j, and β^a is the scaling parameter that reflects the travel behaviour of age group a associated with the travel cost c_{ij}.

The model is therefore able to predict expenditure flowing to the supermarkets from age group a, S_j^a, as

$$S_j^a = \sum_j S_{ij}^a$$

and total expenditure S_j at the supermarket as

$$S_j = \sum_a S_j^a \quad .$$

Note that we can convert easily enough between expenditure and people for we want people visits V_j not expenditure *per se* by applying some appropriate conversion factor where we assume we know this as a simple scalar for each age group γ^a. Then

$$V_j = \sum_a \gamma^a S_j^a \quad .$$

Now we can also introduce a simple model at the supermarket destination end of the trip to account for detailed movements in the market which get greater as the supermarket gets bigger. There are several assumptions that we can make and we will list these as mutually exclusive alternative specifications of the attraction. Then

$$A_j = F_j$$

where the attraction is a simple function of floorspace F_j or

[1] Lakshmanan, J. R. and Hansen, W. G. (1965) A Retail Market Potential Model. *Journal of the American Institute of Planners*, *31*, 134-143.

$$A_j = F_j^{\lambda}$$

where the attractor is a positive power of the floorspace. If those who visit the centre are proportional to the floorspace, then we might think of λ as being 2 and then attraction is the square of the floorspace. This is equivalent to a complete set of links between every square foot of the floorspace. Of course λ is usually less than 2 but greater than 1 but nevertheless this is an agglomeration effect that is determined when the model is calibrated. It might in fact be less than 1, which means that the attraction of the market increases but at a decreasing rate with size.

Now if the store is very big, then as shoppers move through it, then may move from their entry point according to the distance/travel cost from the centre of the market and the attraction of the different areas of the market which we might call f_j . We can specify this as

$$A_j = F_j + \sum_k f_k \exp\left(-\mu_j c_{jk}\right)$$

This is at a small scale within the supermarket and it has its own parameter across all shopping centre zones. This is akin to the effects introduced by Piovani, Zachariadis & Batty (2017)[2] as a nested local function within the centre or market and also used in the same spirit by Ying et al. (2019)[3]. In fact in the last measure if the site is too small, then we can simply use the measure of floorspace by setting to $\mu_j \to \infty$ and the function collapses simply to floorspace. If we did have a good model of movement inside a supermarket other than the very casual one implied in the nested model above, then this is the place where it would be put.

A Note on the Data

The idea is that we model residential location and the expenditure of the population – or in fact the population by age cohort itself at LSOA or MSOA level and that the supermarkets are something like 15000 point locations. Whether or not we aggregate the supermarkets into OAs or LSOAs is something we need to decide but in the event, we know at OA that there is an average of 1.2 supermarkets at this level. Anyway, whatever this is it will affect the attractor and as we group more and more supermarkets into the same destination zone, the nested agglomeration model in the above equation is increasingly relevant because as a shopper enters a zone of aggregated markets, then the distance between these markets needs to be taken account of as above. The travel time matrix between residential zones and supermarkets will be pruned and we will assume that no one makes more than one hour trip to go to a shop. Thus the matrix of possible links is massively pruned but even then we cannot anticipate the precise representation involved. The residential population is classified by age but we will also assume that only one network – an aggregation of the three modal networks or simply the road network – is used for the simulation. Last but not least we need some measure of how many people go to the shopping centres in question. In short we need this data so we can validate the model. Ideally we also need the shopping centre flows but these variables are very hard to get and we may be forced to simply calibrate the model using mean trip lengths from our QUANT journey to work model.

[2] Piovani, D., Zachariadis, V. and Batty, M. (2017) Quantifying Retail Agglomeration using Diverse Spatial Data, **Scientific Reports** | **7**: 5451 | DOI:10.1038/s41598-017-05304-1

[3] Ying, F., Wallis, A. O. G., Beguerisse-Díaz, M., Porter, M. A., and Howison, S. D. (2019) Customer Mobility and Congestion in Supermarkets, **Physical Review E**, **100**, 062304.